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OPTIHUBS - multimodal hub process optimization by means of micro simulation

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Abstract

The development of multimodal hubs is a sensitive task due to numerous parallel occurring processes and external dependencies. There are already isolated solutions available that mostly suffer from a holistic approach. Based on the results of a predecessor research study one objective of the ongoing research project OPTIHUBS is to identify integrated solutions for multimodal hub process optimization via micro simulation technologies for optimizing administrative, operational und logistic processes at inland waterway hubs. Based on the representation of various processes, flexible parameters for transport flows, handling volumes and traffic movements the requirements for existing and potential product groups/cargo types at multimodal nodes are compiled. They form the basis for an optimized workflow management scheme which is not described in this paper. Process parameters are retrieved via observations, terminal data analysis and interviews. Furthermore real-world hub processes are recorded and supplemented. Algorithms are developed based on a catalogue of requirements issued by the research project consortium. The micro simulation tool consists of several elements that allow alterations of parameters such as transport flows, handling volumes/processes and process/time restrictions. In addition the surrounding road/rail/water traffic environment is part of the simulation in order to allow analysis of interdependencies. Results from the simulation exercises will be used at a later point in time in project delivery in order to define a strategy concept for an efficient supply chain/bottleneck analysis.

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1. Introduction

Based on the results of the predecessor research study Hauger et al. (2014) – SMART HUBS 2.0 – the current research project Hauger et al. (2015) – OPTIHUBS - deals with the development of a standardised simulation system with unique algorithms that combines and optimizes significant (administrative, operational und logistic) and innovative processes as well as location based conditions at multimodal hubs. The project consists of several work packages and is programmed for the time period from August 2014 until July 2016. It is sponsored through the third tender of the Austrian R&D call Mobilität der Zukunft of the FFG.

This paper focuses on the integrated solution using innovative micro simulation technologies for optimizing the introduced processes at inland waterway hubs and other terminals. Results from the simulation exercises will be expected in summer 2016 and used by the project consortium to define a strategy concept for an efficient supply chain/bottleneck analysis. Due to the proposed time schedule details of the strategy concept cannot yet be discussed in this paper.

2. Selection of a simulation tool

Prior to the selection of a specific tool a simulation concept was developed in cooperation with all research project partners that also includes strategies how to process and simulate external specifications established by the partners.

In the beginning of the simulation concept development the main obstacle was the willingness of practical project partners (port and terminal operators) to provide input in terms of potential case studies as well as explicit input data. By Mai 2015 a functioning working environment could be established. Consequently the simulation concept was treated as living document and was changed and amended several times. It includes elements that can be modelled on a macroscopic level as well as explicit micro simulation exercises that need a vehicle and process based decision process during each simulation run.

In general there are many different ways to simulate/model multimodal hubs depending on the individual task or specified focus e.g. land use, process and traffic infrastructure optimization. Therefore new approaches need to consider already existing systems and models in place as well as the data availability and in extracts topics such as

- objectives of the optimization exercise
- net model, handling and geographic referencing
- data import and export as well as corresponding interfaces
- data and traffic demand/distribution modelling
- control, handling and manipulation of processes prior and during the simulation runs
- alteration of the demand and handling of changed circumstances of the particular hub
- simulation core
- scenario handling
- deduction of key performance indicators, output reports and
- validation possibilities.

In terms of network development one should consider using open data such as OpenStreetMap (OSM) in order to have alternative data sources in addition to official sources such as municipality authorities where data needs to be requested explicitly. Open data is made increasingly available on an international level which is one of the benefits since the simulation system should be able to handle different hub environments on an international level. In addition personal amendments to the graphs can be made available in exchange to the data provided by the user cloud.

Since the model should be dealing with exercises on macroscopic and microscopic levels a node-line-model should be preferred.

During the initial project phase the following simulation tools were selected and assessed in order to decide upon the most promising approach:

- PTV VISUM/VISSIM (PTV AG, Germany)
- AIMSUN (TSS, Spain)
- PARAMICS, Quadstone (Pitney Bowes USA, GB)
- SUMO (OpenSource, Germany)
- CUBE (Citilabs, USA)
- MATSim (OpenSource, Switzerland, Germany, Singapore)

For evaluation purposes experiences of the project’s simulation team as well as internet based literature reviews and interviews with simulation experts were conducted. Results of the software comparison can be retrieved from table 1.

Table 1. Criteria based review of different software concepts for micro simulation model development.

Criteria	VISUM VISSIM	AIMSUN	PARAMICS	SUMO	CUBE	MATSim
Individual Hub Construction	++	+	+	+	+	0
Procedures (Coverage, Selection)	++	+	0	0	+	+
Node Modelling	++	+	+	+	+	-
Micro Simulation	++	++	+	+	-	+
Scenario Techniques	++	+	+	-	++	-
Hybrid Modelling (Makro-Meso-Mikro)	+	++	+	-		-
Traffic Actuated Program Control	++			+	0	-
Cargo Traffic Modelling	+	--	--	--	+	+
Agent-based Approach	0	--	--	+	0	++
Manuals, Troubleshooting	++	-	--	0	-	0
Interfaces (API)	+	+	+	++	0	++
Open Source Components	-	-	-	++	-	++
Stability and Maintenance Demand	+	+	+	--	0	-

The reviews and assessments in accumulation with the simulation concept lead to the decision to use VISUM/VISSIM of the PTV AG. In terms of future potential requirements regarding the generation of demand of goods MATSim could also be used in addition.

VISUM can be used for the establishment of the basic network with nodes and lines and can provide input for the generation of the simulation environment in VISSIM using the interface for data exchange between both programs. In addition an evaluation can be carried out on different levels of aggregation (macroscopic and microscopic). OSM can be used to import road network elements independent of the current area of investigation thanks the unique coding of the OSM elements. Minor efforts are required to get a routing capable network as basis for investigations. The network nodes are defined automatically based on the start and end points of the imported network line elements.

For visualisation purposes digital background maps can be used such as aerial photography or OSM maps. During simulations 3D-views can be accessed with detailed models of vehicles such as trains, cranes, ships, trailers and cargo units that can be created individually or imported from e.g. the 3D Warehouse – Sketchup. Furthermore the state of these models can be changed in order to reproduce handling processes or container depot areas. Consequently detailed visualisations can be produced which are based on real-time running processes. This is a major benefit in comparison to state-of-the-art visualisations with other programs that are based on static elements.

Apart from defining detailed traffic signal settings in VISSIM the macroscopic counterpart can also be used to define general traffic signal settings and green wave coordination along defined routes of the area of interest which would be running in the background of the simulation and thus affecting certain tasks that are to be assessed with the model.

Detailed vehicle actuated (traffic signal) definitions are one of decisive advantages of the chosen simulation tool since they can be implied with high flexibility in different ways without extensive programming skills. During the simulation concept development phase the vehicle actuated definitions were chosen as most promising option to represent some of the dependencies of different processes and vehicle based decisions. They can further be used to trigger other processes and decisions throughout the simulation runs.

Apart from the already identified advantages the main decisive element of the chosen simulation tool is the pre-defined interface opportunity with Excel and Excel VBA scripts - so called VISSIM-COM. This gathers for nearly unlimited interaction possibilities between data in Excel spreadsheets, algorithms in Excel scripts and Import/Export functions of VISSIM data of nearly each element of the program such as vehicle and simulation based data. This interface has been established in the past years by the provider PTV AG and has already proven high flexibility in terms of programing during the early project phase. Another advantage is the text-based program language of each VISSIM simulation file which allows the user to manipulate and copy individual network elements such as connectors, links, signal groups, detectors and static objects amongst others.

Within OPTIHUBS the interface described above is used to:

- import specified data such as second-by-second interval based vehicle inputs (e.g. vehicle type, desired speed and start location, loading, target terminal, driving behaviour settings) from individually defined Excel spreadsheets that provide all the original data from real-world terminal operation systems (AVSIO-data);
- define simulation settings based on Excel spreadsheet masks prior and during each simulation run that include but are not limited to time constraints (e.g. checking processes), number and types of cargo-handling machinery (e.g. number of reach stackers), priorities of work orders for staff;
- calculate and initiate processes within the simulation run based on generated VISSIM data during the simulation run that is assessed through queries and reference tables;
- export data such as vehicle specific timestamps at different locations as well as details of finished work schedules of each cargo handling machinery in order to derive key performance indicators:

Consequently the following simulation exercises can be:

- reproduction of vehicle based traffic streams (e.g. including the assessment of traffic queuing developments, incidents and over-saturation situations at intersections and key points such as OCR gates)
- flexible definition of specific areas (e.g. definition of access and exit points of the hubs and terminals, interaction of different structures and cargo handling areas)
- reproduction of processes (e.g. analysis of performance, efficiency and effectiveness)
- definition of different priorities of work orders such as priorities of handling incoming vehicles with delays
- definition of different incoming and outgoing amounts of cargo units by type and time

3. Addressing elements within the simulation

The reproduction of processes at individual inland waterway ports and terminals requires an extensive amount of definitions and careful considerations covering various parts of the simulation area such as the following which are described with corresponding examples:

- End-to-end coding of each simulation element e.g. detectors, signal groups, routing decisions and link numbers: the coding needs to be precisely defined since the Excel interface needs to be able to address each individual element or the whole group of elements during specific tasks within the simulation run. In cases of network changes that coding needs to be capable of handling changes and amendments based on new circumstances; example: defining handling areas for trucks with a header and only one digit number T0-T9 will limit it to 10 possible handling areas. Once the terminal environment changes and > 10 handling areas are made available the coding would not be able to gather for the additional areas due to its restricted definition

- Decision of preferred simulation element to reproduce real-world processes: since VISSIM is able to provide vehicle actuated programming there are several different ways to implement these processes and dependencies within the program: one has to decide whether e.g. routes, signal groups, detectors, driving restrictions, stop signs, give way rules or desired speed definitions should be preferred in opposition to the other possibilities in addition to the method how these individual elements are addressed; example: one might use stop signs at truck handling areas in order to stop vehicles at the designated area and start the handling process. These could use different stop time intervals based on statistical distributions but would not allow an individual manipulation of the stop time interval e.g. in case of simulating a vehicle breakdown or problems with clamps on cargo units – vice versa stop signs are easy to implement in the model in comparison to elements such as signal groups.
- Decision of the preferred process interaction within the model: as stated before there are several different ways to address individual elements within the simulation and trigger specific actions based on circumstances and locations of these elements e.g. a truck stopping in the handling area and communicating the model that the cargo unit is now available for processing. Such actions can be triggered as follows but are not limited to the specified example:
  - Decisions based on automatic algorithms in VISSIM such as give way rules and signal group phases for vehicles that do not need any interaction with Excel in order to work
  - Decisions based on Excel VBA script entries that do not need to be accessed by the user throughout the simulation run such as specific points in time where certain actions are triggered such as checking of the cargo handling machinery for new work orders. These decisions need the import of the element number prior to sending the model the required command
  - Decisions based on reference tables in Excel that need the import of the element number prior to sending the model the required command. In this case the data is copied into a pre-defined spreadsheet cell that triggers e.g. a VLOOKUP command that provides required information such as route or signal group.
  - Decisions based on several indicators and reference tables in Excel that also need the import of the element number as well as other inputs and element specifications prior to sending the model the required command. In this case the data is also copied into a pre-defined spreadsheet cell that triggers specific actions e.g. a combination of several Excel based functions.

PTV AG (2012), which provides a manual for VISSIM-COM included relevant input during the decision process in terms of how interaction can be carried out with each of the simulation elements; example: vehicles can usually be addressed through their individual vehicle number that is assigned to them at the import process and is not changed even if the vehicle is leaving the network; but they cannot be addressed through their vehicle names.

4. Development and verification of simulation algorithms

4.1. Difficulties with standard simulation element behaviour

Taking into account the basic elements of the simulation tool VISSIM one has to bear in mind that the original focus of the tool deals with the simulation of individual vehicles within broader vehicle flows. Therefore vehicles are supposed to drive in one continuous direction across the simulation network only stopping at specific locations such as traffic signals, stop signs and according to give way rules and give way areas.

In the field of terminal simulations there is a slightly different approach e.g. with portal cranes that are supposed to move in several directions along a specified railway track or single cargo trailers and coaches that should be able to change their current 3D state e.g. once the cargo handling process is carried out in order to see the difference within the visualisation as well as for algorithm verification purposes. Therefore several algorithms needed to be implemented to take into account the required changes based on the normal simulation behaviour.

4.2. Verification of simulation algorithms

Advantages in building terminal simulation environments from the scratch are certain elements were decisions need to be implemented during the simulation e.g. allocation of designated loading areas for incoming trucks or checking processes of different cargo handling machinery for available work schedules once the current job has been carried out.

At these points during the development phase the programmer needs to think about how these decisions are likewise carried out. Bearing in mind the technical expertise of the corresponding author's company in the field of traffic engineering and planning preliminary algorithms for the decision processes were implemented for several occasions which were then discussed with expert staff of the multimodal hub.

Once discussed the preliminary coding was verified as correct or needed to be amended according to current process structures in place. Consequently the key decisions that are implemented in the model environment at present are able to reproduce real-world decision making processes up to the best possible extent.

A very interesting side effect during development of these preliminary algorithms was the fact that the decision processes could be based on extensive input data made available from the model itself that was not being available in real-world. Therefore the preliminary algorithms proved to be more efficient in some cases than the current real-world decision making processes in place (due to limited data availability).

In addition to the discussions with expert staff synergy effects could be taken into account from Briefer and Zimmermann (2011) who dealt with the analysis and replication of some specific processes of the container terminal that is to be simulated within OPTIHUBS. Consequently the items of the process overview could be analysed by the programmers prior to algorithm development. Furthermore the process overview was assessed in order to ensure that all critical process elements are included in the simulation tool.

Apart from subjective validation efforts also quantitative model validation was carried out based on the available information of specific timestamps at several locations of each processed cargo unit from the real-world terminal management system.

4.3. Innovative data storage for simulation elements

As already mentioned in chapter 3 vehicles and other elements of the simulation would usually be addressed through their unique vehicle number that is assigned to them at the beginning of their simulation existence. Throughout each simulation run VISSIM-COM can access (read and write) specific attributes of each of these elements. For vehicles edible attributes are e.g. name, colour, desired speed, route, position, state, type and weight.

Apart from influencing their current state within the 3D-visualisation these attributes can furthermore be used as data storage in order to trigger specific processes and actions according to the defined process standards of the main algorithms. Some examples among others used in the simulation are:

- Name: it includes the origin and destination of each vehicles and the time of simulation import
- Colour: the colour affects the way how vehicles are treated during different program routines e.g. checking of cargo handling machinery for new work schedules:
  - Blue: Idle cargo handling machinery (e.g. portal cranes, reach stackers) and vehicles without cargo units (e.g. locomotives)
  - Yellow: Cargo handling machinery on the way to the next position and cargo units that have not yet taken into account for the current work schedules of the cargo handling machinery
  - Orange: Cargo handling machinery during handling process
  - Purple: Cargo units on the way to the inspection site
  - Green: Cargo units, that are awaiting the cargo handling process
  - Dark green: Cargo trailers that are only picking up cargo units
  - Grey: Cargo units that have already been processed.
- Link and Position: these items are used to define the input for the Excel based functions and inquiries.

Working with the colour attribute is very comfortable since the colour visually assists during the process of simulation testing. Once the testing is finished the model attributes can be set to static in order to prevent colour changes although VISSIM will still take into account the colour changes in the background that are communicated throughout the simulation.

5. Available input data

Throughout the simulation tool development OPTIHUBS benefited from extensive amounts of terminal data as well as other data sources that are as follows:

- Vehicle permits on a daily base from the in- and out gate of a terminal including the type of vehicle, desired direction and time of entry and exit
- Layouts of proposed (alternative) in- and out gates including details and time intervals for checking periods
- Future potentials in terms of cargo unit types and mode of transport
- Briefer and Zimmermann (2011) - refer to chapter 4.2 for details
- Data from the work schedules of a terminal management system including details about each processed cargo unit and cargo units in stock such as encrypted number and name, length, height, type, condition, loading, weight, status, date and time of arrival and departure, incoming and outgoing mode of transport, incoming and outgoing transport unit, first and last position within the container depot areas, number of manipulations of the cargo unit between the first and last position
- Timestamp from the OCR-Gate of the outgoing road transport units
- Information regarding delays of incoming and outgoing trains
- Information about the setup of the individual trains and corresponding location of each cargo unit
- Map of current and planned terminal layouts
- Container depot information (number and position of cargo units)
- Technical parameters of different cargo handling machinery types
- Traffic signal programs for the area of interest around the port of Vienna

In comparison to other research projects that have already been carried out by the corresponding author's company the amount of input data made available for OPTIHUBS is extraordinary. Consequently the following inputs have already been derived for the simulation tool (additional input will be created along the remaining project time):

- Setup of incoming and outgoing trains and corresponding location of each simulated cargo unit including timestamp of arrival and departure
- Location of the individual loading areas as well as in- and out gates
- Link of incoming and outgoing cargo units and transport units
- Location of incoming road transport units prior to cargo handling
- Background information for all processed cargo units and cargo units in stock to derive key performance indicators and triggering of processes according to different cargo unit types
- Container depot situation (cargo units that won't be accessed throughout the simulation period reduce the availability of container parking positions)

As a backup strategy in case of data unavailability a random data input generator was also developed that creates different types of cargo units and work schedules based on initial parameters about the share of modes of transports and cargo unit types.

6. Key elements of the simulation tool

The simulation tool consists of several elements that are used for the following tasks:

- Definition and handling of parameters prior and during the simulation run
- Processing of individual cargo units including the conduction of pre-checks
- Management of the simulated work schedules for each cargo handling machinery
- Deduction of information regarding each transport vehicle and other simulation elements
- Deduction of information about finished work schedules and corresponding key performance indicators

7. Simulation scenarios and key performance indicators

In cooperation with all project partners of OPTIHUBS several simulation scenarios have been defined. For these scenarios the simulation tool should preferable provide input in terms of potential optimization on different levels of available measures. These scenarios are:

- Analysis of traffic queuing caused by heavy vehicles in conjunction with existing traffic signals at existing and planned in- and out gates of multimodal hubs
- Assessment of the impact of heavy load cargo handling in combination with parallel running “normal” processes
- Effects of different train track lengths on cargo handling and key performance indicators
- Analysis of future layouts and changes in the amount of incoming and outgoing cargo
- Effects of increased cargo transport along the inland waterways and its handling in addition to current handling processes at multimodal hubs
- Effects of different in- and out gate configurations regarding traffic flow, dwell times, processing times, traffic queuing, available loading areas and checking procedures
- Comparison of different cargo handling machinery usage in terms of key performance indicators
- Manipulation of different existing and planned cargo unit types and their effects on container depot areas
- Input for process optimization through increased data availability
- Effects of different measures in terms of cargo unit arrivals

All of these scenarios will include simulations of different settings such as existing and planned configurations in order to be able to provide the requested input for processes optimization. Several key performance indicators are implemented in the model that will be used for assessing the effects of different settings and scenarios. The current setting of the key performance indicators is described in the following table 2.

Table 2. Current setting of OPTIHUBS key performance indicators.

Indicator (Average, Max, Min)	Unit
Cargo unit handling output	tons/hour, tons/day
Storage capacity (per terminal)	cargo units/day
Dwell time	minutes/vehicle
Cargo unit handling time	minutes/cargo unit
Degree of capacity utilization of cargo handling machinery	%

Further performance indicators can also be made available or derived based on data exports from the simulation tool.

8. Description of existing software solutions (state-of-the-art) practises in the field

In terms of hub/terminal simulation different existing software solutions (state-of-the-art) have been analysed in order to identify a potential niche and distinctiveness of the OPTIHUBS methodology and simulation tool. Following key results could be found out and are listed in table 3:

- The majority (8 of 11) of the approaches deal with sea port related developments. The focus of hinterland terminal analysis is only mentioned in one approach form Austria
- Nearly all solutions (sea port and hinterland hub solutions) are focused on standardised container handling activities and have been developed to focus on standardized tasks and handling schemes
- The main area of investigation is limited to the hub area and the arrival/departure of cargo unit
- Performance indicators are derived in most concepts taking into account total or individual cargo volume results

Table 3. Description of existing approaches/software solutions in comparison to OPTIHUBS.

Approach/Software Solution Name	Terminal Type	Unit Tracking	Cargo Unit Types	Area of Investigation	Visualisation
Toolbar Planner	Offshore Terminals Sea Ports	?	Container	Port Cargo Handling	3D-view
Anylogic	Sea Ports	Yes	Container	Port Cargo Handling	3D-view
Simio	Container Terminals	?	Container	Port Cargo Handling	3D-view
Elbsimulation	Waterways between Terminal	No	-	Elb River Area	Map
CHESSCON	Sea Ports	No	Container	Port Cargo Handling	3D-view
FlexSim CT	Offshore Terminals Sea Ports	Yes	Container	Port Cargo Handling	3D-view
MHI Simulator	Automated Container Terminal (Sea Ports)	?	Container	Port Cargo Handling	3D-view
ARENA	Sea Ports	?	Container	Port Cargo Handling	Tables / Charts
SimCont I / II	Hinterland Container Terminal	?	Container	Cargo Handling	Map
MINT	Hinterland Terminal	No	-	Terminal networks	Tables / Charts
SSC Secure Supply Chains	Hinterland Terminal	No	-	Terminal networks	Tables / Charts
optihubs	Hinterland Terminal	Yes	Various Cargo Types Trailers	Cargo Handling / Access Infrastructure Interdependencies	3D-view

Bearing in mind the results of the state-of-the-art comparison there are several elements in OPTIHUBS that highlight the distinctiveness against other existing approaches/solutions. In comparison to sea ports which are connected to the surrounding area by high capacity infrastructures the hinterland terminals are mostly imbedded in grown suburban city structures. The surrounding road and rail infrastructure needs to provide capacities not only limited to the hub activities. Consequently there are numerous interdependencies between the hub and its environment that can be incorporated in the proposed approach. Different scenarios, access and departure routes and impacts of e.g. delays can be simulated, analysed and visualised.

In addition the model can easily be modified to gather for special cases such as cargo unit handovers between adjacent portal cranes which cannot be taken into account with most of the identified existing solutions. Apart from the key performance indicators further on-demand performance indicators can be defined to meet special analysis purposes.

In contrast to other solutions the model is able to take into account several different cargo types and vehicle trailers together with their limitations and handling/storing requirements. This includes realistic driving behaviour of road/cargo handling vehicles in the vicinity of access/departure/cargo handling points of the hub and surrounding road network elements such as intersections, traffic signals, roundabouts, and parking areas which gather for the availability of cross validation of proposed changes such as e.g. turning curves. This is beyond existing methodologies that mainly provide limited levels of vehicle manoeuvrability.

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